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(54) **ENHANCED CRT ENABLEMENT BASED ON SOOT MASS STORED IN PARTICULATE FILTER**

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(57) **ABSTRACT**

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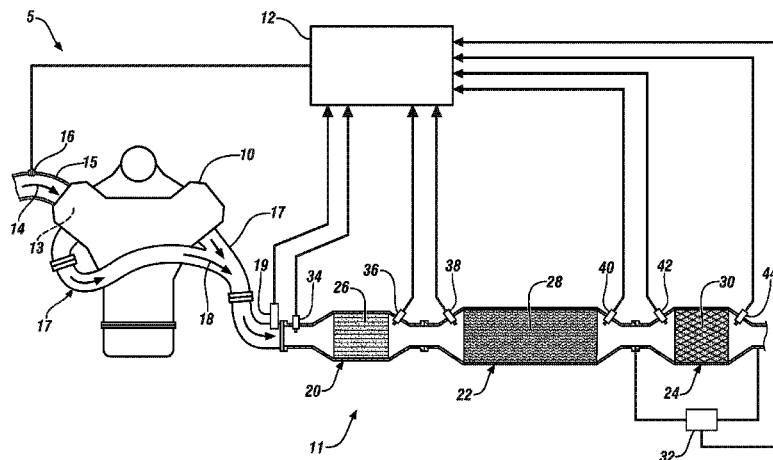
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An exhaust treatment system to treat exhaust gas includes a particulate filter and a pressure sensor. The particulate filter is configured to trap soot contained in exhaust gas. The pressure sensor is configured to output a pressure signal indicative of a pressure differential of the particulate filter. The exhaust treatment system further includes a soot mass module configured to determine a soot mass. The soot mass is indicative of an amount of soot stored in the particulate filter based on the pressure differential and a soot model stored in a memory device. The exhaust treatment system further includes a continuously regenerating trap (CRT) compensation module configured to generate a variable CRT threshold. The CRT compensation module selectively outputs a CRT compensation value that modifies the soot model based on comparison between the NO_x flow rate and the soot mass-based variable CRT threshold.

(52) **U.S. Cl.**

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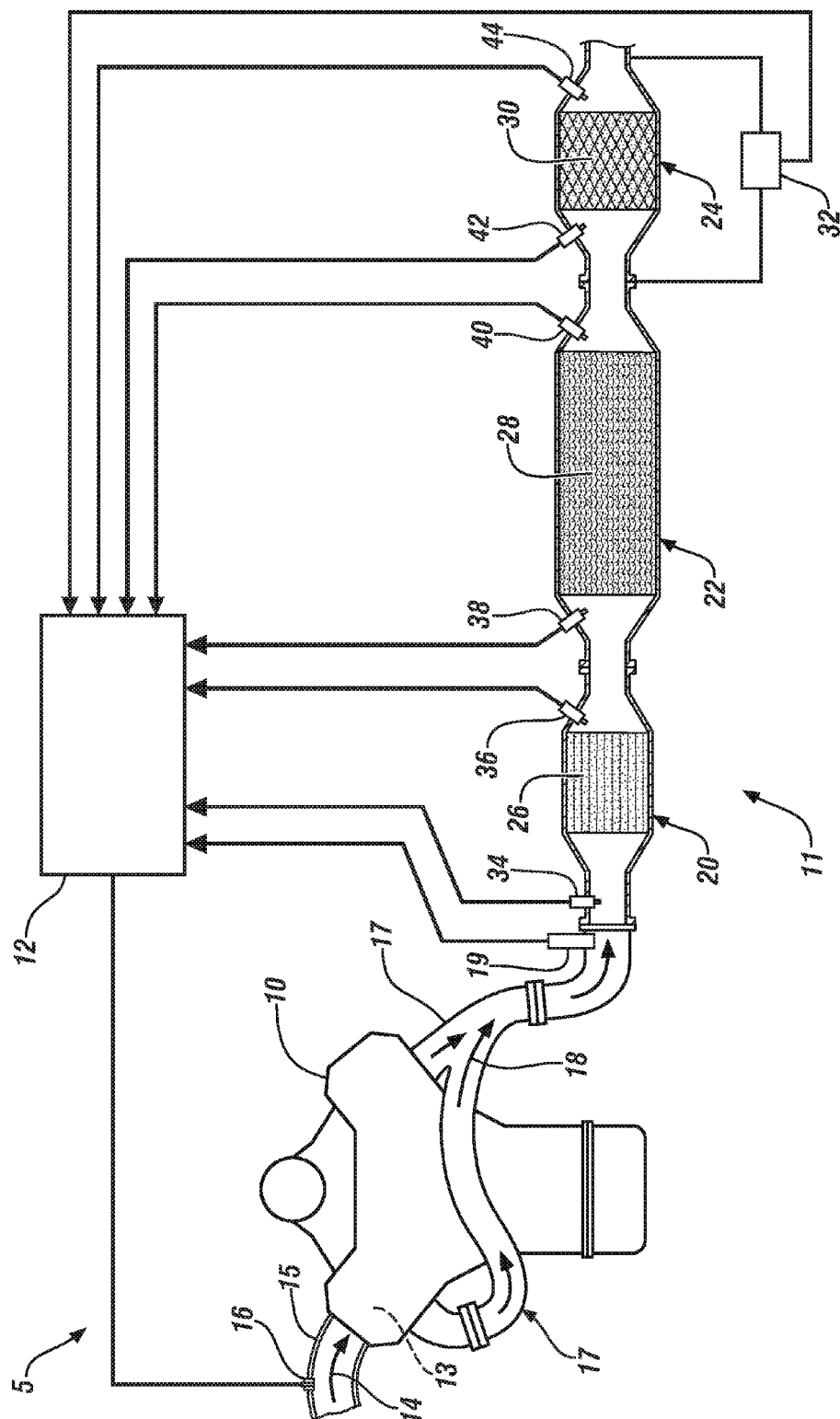


FIG. 1

FIG. 3

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ENHANCED CRT ENABLEMENT BASED ON SOOT MASS STORED IN PARTICULATE FILTER

FIELD OF THE INVENTION

The present disclosure relates to exhaust treatment systems, and more particularly to, estimating soot mass stored on an after-treatment device of an exhaust treatment system.

BACKGROUND

Vehicle exhaust treatment systems are used to reduce undesired emissions, such as oxides of nitrogen (NO_x) and particulate matter (e.g., soot) output by the vehicle engine. The vehicle exhaust systems typically include a particulate filter ("PF"), which traps the soot from the exhaust gas generated by the engine. The PF may include one or more filter substrates that define a plurality of apertures, through which the exhaust gas must flow. The particulate matter collects on the filter substrate as the exhaust gas flows through the apertures. A regeneration operation may be performed to burn away the collected particulate matter and regenerate the PF. The regeneration operation heats the particulate filter to a combustion temperature sufficient to combust (i.e., burn) the collected particulate matter.

One or more regeneration events for initiating the regeneration operation may be determined according to a soot model. The soot model may be used to estimate and predict soot accumulation on the particulate filter, which may indicate the desirability to perform the regeneration operation. However, changes in the temperature at which an engine operates can cause appreciable variations in quantities of soot carried in the engine exhaust stream. Conventional exhaust treatment systems have attempted to compensate for variations in the quantity of soot loading during low operating conditions, such as urban driving condition, by applying a single non-varying (i.e., static) continuously regenerating trap (CRT) correction factor to the soot model based on NO_x levels in the exhaust gas.

SUMMARY OF THE INVENTION

In one exemplary embodiment of the present disclosure, an exhaust treatment system to treat exhaust gas includes a particulate filter and a pressure sensor. The particulate filter is configured to trap soot contained in exhaust gas. The pressure sensor is configured to output a pressure signal indicative of a pressure differential of the particulate filter. The exhaust treatment system further includes a soot mass module configured to determine a soot mass. The soot mass is indicative of an amount of soot stored in the particulate filter based on the pressure differential and a soot model stored in a memory device. The exhaust treatment system further includes a continuously regenerating trap (CRT) compensation module configured to generate a variable CRT threshold and to selectively output a CRT compensation value that modifies the soot model based on a comparison between the NO_x flow rate and the soot mass-based variable CRT threshold.

In another exemplary embodiment of the disclosure, a hardware control module is configured to dynamically modify a soot model that indicates a soot mass stored on a particulate filter. The hardware control module comprises a memory device, a soot mass module and a continuously regenerating trap (CRT) compensation module. The memory device is configured to store the soot model. The soot mass module is configured to determine the soot mass based on the

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soot model and a pressure differential between an inlet and an outlet of the particulate filter. The CRT compensation module is in electrical communication with the soot mass module. The CRT module is configured to generate a CRT compensation value that modifies the soot model. The CRT module is further configured to generate a CRT threshold that varies as the soot mass stored in the particulate filter changes.

In yet another exemplary embodiment of the disclosure, a method of controlling an exhaust treatment system of a vehicle comprises trapping soot contained in exhaust gas flowing through a particulate filter. The method includes determining a pressure differential between an inlet of the particulate filter and an outlet of the particulate filter. The method further includes determining a soot mass indicative of an amount of soot stored in the particulate filter based on the pressure differential and a soot model. The method further includes generating a CRT compensation value and a variable CRT threshold. The method further includes comparing the NO_x level to the variable CRT threshold and selectively applying the CRT compensation value to the soot model such that the soot model is modified based on the comparison.

The above features of the present disclosure are readily apparent from the following detailed description when taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features and details appear, by way of example only, in the following detailed description of embodiments, the detailed description referring to the drawings in which:

FIG. 1 is a schematic diagram of a vehicle system including an exhaust treatment system having a vehicle control module that dynamically modifies a soot model for determining soot mass of a particulate filter according to an embodiment of the present disclosure;

FIG. 2 is a block diagram illustrating a control module that modifies a soot model based on a dynamic CRT enablement operation according to an embodiment of the present disclosure; and

FIG. 3 is a flow diagram illustrating a method for dynamically enabling a CRT compensation operation to modify a soot model according to an exemplary embodiment of the present disclosure.

DESCRIPTION OF THE EMBODIMENTS

The following description is merely exemplary in nature and is not intended to limit the present disclosure, its application or uses. It should be understood that throughout the drawings, corresponding reference numerals indicate like or corresponding parts and features.

As used herein, the term module refers to a hardware module including an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable components that provide the described functionality. In at least one embodiment of the present disclosure, a module may include a microcontroller as understood by those ordinarily skilled in the art.

Referring now to FIG. 1, a vehicle system 5 is generally shown according to an embodiment of the present disclosure. The vehicle system 5 includes an internal combustion (IC) engine 10, an exhaust gas treatment system 11, and a vehicle control module 12. The engine 10 may include, but is not limited to, a diesel engine, gasoline engine, and a homogeneous charge compression ignition engine. The engine 10

includes at least one cylinder **13** configured to receive fuel, and intake air **14** from an air intake passage **15**. The air intake passage **15** includes a mass air flow (MAF) sensor **16** to determine an intake air mass (m_{Air}) of the engine **10**. In one embodiment, the MAF sensor **16** may include either a vane meter or a hot wire type intake mass air flow sensor. However, it is appreciated that other types of sensors may be used as well. An exhaust gas conduit **17** may convey exhaust gas **18** that is generated in response to combusting the fuel and air **14** in the cylinder **13**. The exhaust gas conduit **17** may include one or more segments containing one or more aftertreatment devices of the exhaust gas treatment system **11**, as discussed in greater detail below. A NO_x sensor **19** may be disposed downstream from the engine **10** to determine an amount of NO_x (e.g. NO_{x,MASS}) present in the exhaust gas **18** and/or a NO_x flow rate (e.g., NO_{x,RATE}).

The exhaust gas treatment system **11** described herein can be utilized with any of the engine systems described above to reduce exhaust gas constituents generated during combustion. The exhaust gas treatment system **11** generally includes one or more exhaust treatment devices. The exhaust treatment devices include, but are not limited to, an oxidation catalyst device ("OC") **20**, and a selective catalytic reduction ("SCR") device **22**, and a particulate filter ("PF") **24**. In at least one exemplary embodiment of the disclosure, the PF **24** is a diesel particulate filter. As can be appreciated, the exhaust gas treatment system **11** of the present disclosure may include various combinations of one or more of the exhaust treatment devices shown in FIG. 1, and/or other exhaust treatment devices (not shown) and is not limited to the present example. For example, an individual PF **24** may be disposed downstream from a separate SCR device **22**.

In FIG. 1, the exhaust gas conduit **17**, which may comprise several segments, transports exhaust gas **18** from the engine **10** to the various exhaust treatment devices **20**, **22**, **24** of the exhaust gas treatment system **11**. As can be appreciated, the OC **20** can be of various flow-through, oxidation catalyst devices known in the art. In various embodiments the OC **20** may include a flow-through metal or ceramic monolith substrate **26** that is wrapped in an intumescent mat or other suitable support that expands when heated, securing and insulating the substrate. The substrate **26** may be packaged in a stainless steel shell or canister having an inlet and an outlet in fluid communication with the exhaust gas conduit **17**. The substrate **26** can include an oxidation catalyst compound disposed thereon. The oxidation catalyst compound may be applied as a washcoat and may contain platinum group metals such as platinum (Pt), palladium (Pd), rhodium (Rh) or other suitable oxidizing catalysts, or combination thereof. The OC **20** is useful in treating unburned gaseous HC and CO, which are oxidized to form carbon dioxide and water.

The SCR device **22** may be disposed downstream of the OC **20**, and is configured to reduce NO_x constituents in the exhaust gas. As can be appreciated, the SCR device **22** may be constructed of various materials known in the art. In various embodiments, the SCR device **22** includes an SCR substrate **28**. A SCR catalyst composition (e.g., a SCR washcoat) may be applied to the SCR substrate **28**. The SCR device **22** may utilize a reductant, such as ammonia (NH₃) to reduce the NO_x. More specifically, the SCR device **22** catalyst composition can contain a zeolite and one or more base metal components such as iron (Fe), cobalt (Co), copper (Cu) or vanadium (V) which can operate efficiently to convert NO_x constituents in the exhaust gas in the presence of NH₃. The reductant utilized by the SCR device **22** may be in the form of a gas, a liquid, or an aqueous urea solution and may be mixed with air to aid in

the dispersion of an injected spray generated by a reductant supply system as known to those ordinarily skilled in the art.

The PF **24** may be disposed downstream from the SCR device **22**, and filters the exhaust gas **18** of carbon and other particulate matter (e.g., soot). The PF **24** has an inlet and an outlet in fluid communication with exhaust gas conduit **17** to convey exhaust gas **18** therethrough. According to at least one exemplary embodiment, the PF **24** may be constructed using a ceramic wall flow monolith exhaust gas filter substrate **30** that is wrapped in an intumescent or non-intumescent material (not shown). The filter substrate **30** may expand when heated to secure and insulate the filter substrate **30** which is packaged in a rigid, heat resistant shell or canister. It is appreciated that the ceramic wall flow monolith filter substrate **30** is merely exemplary in nature and that the PF **24** may include other filter devices such as wound or packed fiber filters, open cell foams, sintered metal fibers, etc. The exhaust gas treatment system **11** may perform a regeneration operation that regenerates the PF **24** by burning off the particulate matter trapped in the filter substrate **30**. Various systems known to those ordinarily skilled in the art (e.g., active regeneration systems and/or passive regeneration systems) may be used for performing the regeneration operation to regenerate the PF **24**.

The exhaust gas treatment system **11** may further include at least one pressure sensor **32** (e.g., a delta pressure sensor), as illustrated in FIG. 1. The delta pressure sensor **32** may determine the pressure differential (i.e., Δp) across the PF **24** (e.g., between the PF inlet and the PF outlet). Although a single delta pressure sensor **32** is illustrated, it is appreciated that a plurality of pressure sensors may be used to determine Δp . For example, a first pressure sensor may be disposed at the inlet of the PF **24** and a second pressure sensor may be disposed at the outlet of the PF **24**. Accordingly, the difference between the pressure detected by the second delta pressure sensor and the pressure detected by the first delta pressure sensor may indicate the Δp of the PF **24**.

In addition to pressure sensors, the exhaust gas treatment system **11** may include one or more temperature sensors. According to at least one exemplary embodiment of the present disclosure, the exhaust gas treatment system **11** may include temperature sensors **34-44**. Although six temperature sensors are described, the number of temperature sensors illustrated in FIG. 1, however, is not limited thereto. First temperature sensor **34** and second temperature sensor **36** are disposed at the inlet and outlet of the OC **20**, respectively, and may determine a temperature of the OC substrate **26**. Third temperature sensor **38** and fourth temperature sensor **40** are disposed at the inlet and outlet of the SCR device **22**, respectively, and may determine a temperature of the SCR device **22**. Fifth temperature sensor **42** and sixth temperature sensor **44** are disposed at the inlet and outlet of the PF **24**, respectively, and may determine a temperature of the filter substrate **30**.

The vehicle control module **12** controls one or more operations of the engine **10** and/or the exhaust gas treatment system **11** based on measurements provided by one or more sensors and/or operating models. According to at least one exemplary embodiment, the vehicle control module **12** may control the regeneration operation, which regenerates the PF **24** when a regeneration event occurs. The regeneration operation heats the particulate filter **30** to a temperature sufficient to combust (i.e., burn) the collected soot.

One or more regeneration events may trigger the regeneration operation. The vehicle control module **12** may determine a regeneration event according to a soot model stored in a memory device. The soot model may be used to estimate and

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predict the amount (i.e., mass) of soot accumulated by the filter substrate **30** of the PF **24**. The mass of accumulated soot may be set as a basis for performing the regeneration operation. According to at least one exemplary embodiment, the soot model is based on Δp , a temperature of the filter substrate **30** (T_s), NO_{xRATE} , and an exhaust gas volume flow rate (dvol). The dvol may be determined using m_{Air} measured by the MAF sensor **16** and an amount of fuel injected into the cylinders **13** as known by those ordinarily skilled in the art. It is appreciated that the soot model described above is not limited to the aforementioned measurements and additional operating parameters may be taken into account.

In addition to controlling the regeneration option according to the soot model, the vehicle control module **12** determines a compensation value (hereinafter referred to as a CRT compensation value) that is applied to the soot model to compensate for variations in Δp for a given soot loading during operation of the engine **10**. Conventional CRT compensation systems utilize only the amount of NO_x or the NO_x flow rate to determine when to apply correction factor to the soot model. The conventional correction factor is then calibrated (i.e., applied) according to a single low-level scalar NO_x threshold, above which the model applies the same level of compensation to the soot loading for all levels of NO_x present in the PF **24**. Accordingly, the soot model is conventionally corrected based only on the NO_x concentration or NO_x flow rate of the exhaust gas **18**.

The vehicle control module **12** according to the present disclosure generates a CRT compensation value based on the amount of soot (i.e., soot mass) accumulated in the filter substrate **30** of the PF **24**. Moreover, unlike the conventional CRT correction factor, which is a single static (i.e., non-varying) scalar value, the vehicle control module **12** executes a dynamic CRT enablement operation for modifying the soot model to compensate for variations in soot loading cause by changes in Δp of the PF **24**. More specifically, the vehicle control module **12** generates a varying CRT threshold, which varies as the soot mass accumulated in the filter substrate **30** changes. Accordingly, the CRT compensation value is selectively applied in a variable manner as the soot mass accumulated in the filter substrate **30** changes. That is, the vehicle control module **12** enables the CRT compensation as a function of soot mass, as opposed to a single scalar NO_x threshold. As a result, the accuracy and precision of the soot model may be improved, and premature regeneration of the PF **24** may be avoided.

Turning now to FIG. 2, a block diagram illustrates a vehicle control module **12** that modifies a soot model based on a dynamic CRT enablement operation according to an embodiment of the present disclosure. Various embodiments of the vehicle system **5** may include any number of sub-modules embedded within the vehicle control module **12**. As can be appreciated, the sub-modules shown in FIG. 2 may be combined or further partitioned as well. Inputs to the vehicle control module **12** may be sensed from the exhaust gas treatment system **11**, received from other control modules, for example an engine control module (not shown), or determined by other sub-modules.

As illustrated in FIG. 2, the vehicle control module **12** according to at least one embodiment includes a memory **102**, an entry condition module **104**, a soot mass module **106**, and a CRT compensation module **108**. Each of the modules **104-108** interfaces and electrically communicates with the memory **102** to retrieve and update stored values as needed.

The memory **102** may store one or more threshold values, time periods over which the temperatures were measured a number of configurable limits, maps, data values, variables,

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and system models used to perform the regeneration operation. In at least one embodiment of the present disclosure, the memory **102** stores various parameters including, but not limited to, dvol, specific heat constants, and dimensions of the PF **24**.

The entry condition module **104** may determine if one or more entry conditions exist based on one or more operating condition signals **200** output from one or more sensors of the vehicle. For example, the entry condition module **104** may compare operating conditions to one or more threshold values stored in the memory **102**. Based on the comparison, the entry condition module **104** generates an entry condition signal **202** indicating that the entry conditions are satisfied.

The soot mass module **106** determines an amount (i.e., mass) of soot trapped in the filter substrate **30**, and outputs a soot mass signal **211** indicating the soot mass. More specifically, pressure drop across a loaded after-treatment component (e.g., the PF **24**) and data indicating the relationship between soot accumulation and pressure drop may be used to estimate the extent of soot loading in the filter substrate **30**. Accordingly, the soot mass module **106** may store a soot mass model, which determines the soot mass based on Δp , T_s , NO_{xRATE} , and dvol. The Δp is determined using a Δp signal **204** output from the Δp sensor **32**. The T_s may be determined using one or more temperature signals **206** output from the fifth temperature sensor **42**, and/or the sixth temperature sensor **44**, and/or a temperature model. The NO_{xRATE} is determined using a NO_x signal **208** output from the NO_x sensor **19**. As mentioned above, dvol may be determined using m_{Air} indicated by a m_{Air} signal **210** output from the MAF sensor **16**.

The CRT compensation module **108** is in electrical communication with the soot mass module **106** and receives a soot mass signal **211** indicating the soot mass of the filter substrate **30**. The CRT compensation module **108** also receives a second T_s signal **212** indicating T_s , and the NO_x signal **208**. It is appreciated that the CRT compensation module **108** may receive the temperature signal **206** simultaneously with the soot mass module to determine T_s . Based on the soot mass, T_s and NO_x , the CRT compensation module **108** generates a CRT compensation value that modifies the soot model to compensate for variations in soot loading behavior.

The CRT compensation module **108** further determines a dynamic CRT threshold (TH_{CRT}) that varies as the soot mass on the filter substrate **30** changes. That is, the CRT compensation module **108** performs a dynamic CRT enablement operation by generating the CRT compensation value as a function of the changing soot mass stored on the filter substrate **30**. The TH_{CRT} may include a CRT threshold value, or a CRT threshold range defined by a lower threshold value and an upper threshold value. In at least one embodiment, the CRT threshold is based on a NO_x concentration or a NO_x flow rate indicated by the NO_x signal **208**. As the CRT threshold varies according to the soot mass, the CRT compensation module **108** compares the NO_x signal **208** to TH_{CRT} . If the NO_x signal **208** exists outside TH_{CRT} , the CRT compensation module **108** outputs a CRT compensation signal **214** to the soot mass module **106** indicating the CRT compensation value. The soot mass module **106** applies the CRT compensation value to the soot model to determine an updated soot mass accordingly. The soot mass module **106** may also generate an updated soot mass signal **216** indicating the updated soot mass.

Turning now to FIG. 3, a method for dynamically enabling a CRT compensation operation to modify a soot model is illustrated according to an exemplary embodiment of the present disclosure. The method begins at operation **300**, and

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proceeds to operation **302** to determine whether one or more entry conditions exist. If the entry conditions do not exist, the method returns to operation **302** and continues monitoring for entry conditions. If the entry condition exists, the method determines soot mass of a filter substrate included in a PF at operation **304**. At operation **306**, a variable CRT threshold is determined. The variable CRT threshold is based on, for example, a concentration of oxides of nitrogen (NO_x) in the exhaust gas, a NO_x flow rate, and varies according to the soot mass. At operation **308**, the concentration of NO_x and/or NO_x flow rate is compared to the variable CRT threshold, which varies according to the soot rate as discussed above. If the concentration NO_x and/or NO_x flow rate is within the CRT threshold, the soot model is not modified (i.e., the CRT compensation operation is disabled) at operation **310**, and the method ends at operation **312**. However, if the NO_x and/or NO_x flow rate is not within the threshold, the CRT compensation operation is enabled at operation **314**. The CRT compensation operation includes determining a CRT compensation value and applying the CRT compensation value to the soot model such that the soot model is modified. At operation **316**, an updated soot mass is determined based on the modified soot model, and the method ends at operation **312**.

While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed, but that the invention will include all embodiments falling within the scope of the application.

What is claimed is:

1. An exhaust treatment system to treat exhaust gas of an internal combustion engine, the exhaust treatment system comprising:

- a particulate filter configured to trap soot contained in the exhaust gas flowing therethrough;
- a pressure sensor that outputs a pressure signal indicative of a pressure differential between an inlet of the particulate filter and an outlet of the particulate filter;
- a soot mass module including a microprocessor and electronic memory storing non-transitory computer readable instructions that when executed by the microprocessor, determines a soot mass indicative of an amount of soot stored in the particulate filter based on the pressure differential and a soot model stored in a memory device;
- a continuously regenerating trap (CRT) compensation module including a microprocessor and electronic memory storing non-transitory computer readable instructions that when executed by the microprocessor, generates a variable CRT threshold based on the soot mass and to selectively output a CRT compensation value that modifies the soot model based on a comparison between a NO_x flow rate and the variable CRT threshold; and
- a particulate filter regeneration system configured to perform a regeneration operation that heats the particulate filter to combust the soot based on the modified soot model.

2. The exhaust treatment system of claim **1**, wherein the CRT threshold continuously varies as the soot mass changes.

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3. The exhaust treatment system of claim **2**, wherein the CRT compensation module outputs the CRT compensation value when the soot mass is not within the CRT threshold.

4. The exhaust treatment system of claim **3**, wherein the CRT threshold is based on one of a concentration of oxides of nitrogen (NO_x) in the exhaust gas or a NO_x flow rate.

5. The exhaust treatment system of claim **4**, wherein the CRT threshold includes a first threshold value and a second threshold value greater than the first threshold value, the first and second threshold values defining a CRT threshold range.

6. A hardware control module including a microprocessor and electronic memory storing non-transitory computer readable instructions that when executed by the microprocessor is configured to dynamically modify a soot model that indicates a soot mass stored on a particulate filter, the hardware control module comprising:

an electronic memory device configured to store the soot model;

a soot mass module including electronic memory storing non-transitory computer readable instructions that when executed by the microprocessor determines the soot mass based on the soot model and a pressure differential between an inlet and an outlet of the particulate filter; and

a continuously regenerating trap (CRT) compensation module in electrical communication with the soot mass module, the CRT module including electronic memory storing non-transitory computer readable instructions that when executed by the microprocessor generates a CRT compensation value that modifies the soot model, and to generate a CRT threshold that varies as the soot mass stored in the particulate filter changes,

wherein the hardware control module is configured to control a particulate filter regeneration system configured to perform a regeneration operation that heats the particulate filter to combust the soot mass based on the modified soot model.

7. The hardware control module of claim **6**, wherein the CRT compensation module electrically communicates the CRT compensation value to the soot mass module based on a comparison between the soot mass and the CRT threshold.

8. The hardware control module of claim **7**, wherein the CRT compensation module electrically communicates the CRT compensation value to the soot mass module when the soot mass is not within the CRT threshold.

9. The hardware control module of claim **8**, wherein the soot model applies the CRT compensation value to the soot model to modify the soot model and determines an updated soot mass based on the modified soot model.

10. The hardware control module of claim **9**, wherein the CRT threshold may include one of a CRT threshold value, or a CRT threshold range defined by a lower threshold value and an upper threshold value that is greater than the lower threshold value.

11. The hardware control module of claim **10**, wherein the CRT threshold is based on the soot mass.

12. A method of controlling an exhaust treatment system of a vehicle, the method comprising:

trapping soot contained in exhaust gas flowing through a particulate filter;

determining a pressure differential between an inlet of the particulate filter and an outlet of the particulate filter;

determining a soot mass indicative of an amount of soot stored in the particulate filter based on the pressure differential and a soot model;

generating a CRT compensation value and a variable CRT threshold;

comparing the NOx flow rate to the CRT threshold;
selectively applying the CRT compensation value to the
soot model such that the soot model is modified based on
the comparison; and
regenerating the particulate filter to combust the soot stored 5
on the particulate filter based on the modified soot
model.

13. The method of claim **12**, further comprising continu-
ously varying the CRT threshold as the soot mass stored in the
particulate filter changes. 10

14. The method of claim **13**, further comprising applying
the CRT compensation value when the soot mass is not within
the CRT threshold.

15. The method of claim **14**, further comprising generating
the CRT threshold based on the soot mass. 15

16. The method of claim **15**, wherein the CRT threshold
includes a first threshold value and a second threshold value
greater than the first threshold value, the first and second
threshold values defining a CRT threshold range.

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